PLANETARY DRILLING AUTOMATION BLIND TESTS.

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Introduction: Commercial drilling, even deep-sea or remote, depends on human teleoperation. Lightspeed delays mean that coring and drilling beyond the Moon requires automation in order to not get stuck or risk mission failure. The Drilling Automation for Mars Exploration (DAME) is a NASA project for developing critical-path drilling software technologies.

The DAME project's purpose was to develop and field-test drilling automation and robotics technologies for projected use in missions in the 2011-15 period [1]. Figure 1 shows a lightweight, planetary-prototype drill, in DAME summer Arctic field testing [2]. DAME included control of the drilling hardware, and state estimation of both the hardware and the lithography being drilled and the state of the hole.

Earlier DAME tests in 2004-2006 were conducted under field conditions in frozen fallback breccia in an impact crater (Haughton Crater) in Arctic Canada [2, 3]. While this was a good Mars analog (and hence a realistic environment to test Mars drilling automation), it lacks repeatability or precise knowledge of the drilling target, which in turn renders test results somewhat anecdotal. In 2007, tests at a JPL-developed Mars environment drilling testbed were conducted to provide a rigorous test of drilling automation, and provided calibration of the testbed by comparison with the past Arctic field testing experience.

Fig. 1. DAME planetary drill prototype at Devon Island analog test site (Haughton Crater), 2004-06.

Flying any drill seems unlikely without adequate demonstration, prior to technology cutoff dates, of hands-off automated drilling in a high-fidelity flight-simulated environment. Currently-proposed Mars missions proposed for the next decade which could include robotic drilling, such as ESA's ExoMars, a possible next Scout opportunity for 2013, or the 2016 Astrobiology Laboratory or mid-rover mission scenarios, call for no more than a limited number of sols to be spent drilling. Yet they also call for a series of 0.2-2m depth holes in several sampled target areas. Without hands-off drilling automation, it is estimated that multiple sols would be required to drill each 1-2m hole and the drill would be much more likely to get stuck. And a stuck drill is a critical mission failure, particularly in a rover mission.

Drilling automation is therefore a means to mitigate and reduce the potential mission-critical risks of drill failure. Without confidence in this mitigation, a drill will be difficult to manifest on future missions.

The DAME project's objectives [4] were therefore to first conduct manual low-power dry drilling under relevant conditions, both in the laboratory and at an analog site, in order to discover and model the behavior of the drill under a range of operating conditions including problems and faults. Then in the second year, to take initial software controls and diagnostic models and place them in observation (but not control) of the drill in the same drilling locations and conditions. Then with the knowledge gained from these tests, to refine the automation, close the control and operations loop and in a third year to test hands-off drilling in the same drilling locations and conditions.

Approach: The DAME approach [3,4] is to apply three types of automation:

(a) real-time limit-checking and safing;

(b) near-real-time vibration measurement and fast frequency-domain pattern-matching using a neural net; and,

(c) monitoring system state parameters and inferring system state using both rule-based and model based diagnostic techniques.

DAME had one ongoing, natural input source of drill excitation -- the normal rotation of the drill string or the auger tube. A single type of noncontact sensor – two laser vibrometers (LDV) -- were used in DAME, employing speckle interferometry along with with real-time Fourier transforms over moving measurement windows. These resulted in identified natural frequencies and mode shapes of the drill shaft, which in turn became inputs to a neural network to perceive and identify different drilling and fault conditions.

For repeatable tests, three windowed specimen columns 30cm-square in area and 1m high were constructed (one at Honeybee Robotics, two at JPL) to hold layers of simulant and harder rocks. Initial tests were into known materials, including limestone, sand, basalt, and thin layers of granite (used to simulate ice layers). A downward view into a specimen column is in Figure 2. For later tests, a separate team built up sequences of materials not revealed to the DAME team until post-test analyses. These blind, but reproducible drilling tests were a rigorous means to verify the DAME drilling automation technologies.

Fig. 2. Looking downward into layers of simulant (simulated regolith, granite, basalt, bricks)

Results: A set of dry-run tests at Honeybee Robotics in September 2007 were used to test and integrate the modified DAME system before deployment. From 22 October – 2 November 2007 at JPL, existing DAME capabilities were extended and demonstrated in a series of controlled, repeatable tests into simulated Mars and lunar regolith columns. Spacecraft-level mass (downward force limits) and power limits (<110W) were maintained. A new subsurface testbed facility at JPL Bldg. 141 was initiated, shown in Figure 3. The automation software, shown active in Figure 4, successfully guided the Honeybee 48-mm diameter auger through 3.3m of hands-off drilling, during 35 hours of automated operations spread over the two weeks. Five (of six) known major faults and off-nominal drilling modes were induced, and these were all detected, recovered, and drilling later resumed.

Conclusions: These tested automation and control capabilities make drilling and coring feasible beyond a few centimeters depth, and plausible to include 1-2m class drilling in 2010s mission proposals. The DAME project has developed hardware and software, complementary diagnostic approaches, and completed a series of field tests in a relevant environment, leading to drilling automation maturation suitable for consideration in future missions.

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Fig 3. Drill automation software was tested in October 2007 at a new JPL test facility.

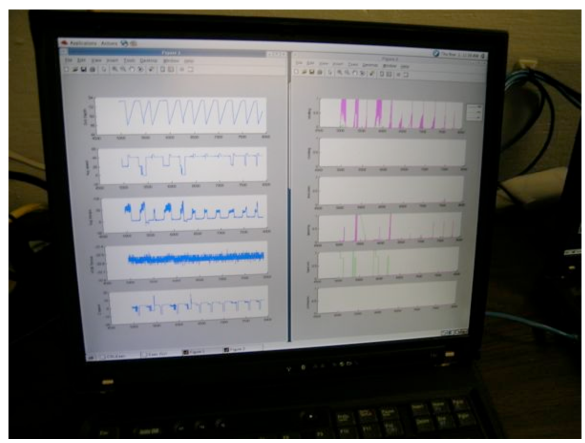

Fig. 4. Drilling System Parameters (blue) with DAME State Hypotheses (right screen).

References:[1]Glass, B. et al. (2006) *AIAA Space 2006.* [2]Paulsen, G.L. et al. (2006), *LPSC XXXVII,* Abstract 2358. [3]Glass, B. et al. (2007) *LPSC XXXVIII*, Abstract 1914. [4] Zacny, K. et al. (2007) *LPSC XXXVIII*, Abstract 1765.